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Talus measurements as a diagnostic tool for sexual dimorphism in Egyptian population

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ABSTRACT

Measurements of talus have been shown to be sexually dimorphic in South African blacks and whites and Prehistoric New Zealand Polynesians. Since several studies have demonstrated that discriminant function equations used to determine the sex of a skeleton are population specific, the purpose of the present study was to derive similar equation for the tali of Egyptians. The sample consisted of 110 tali (67 male & 43 female) whose age at death ranged between 20 and 60 years. The tali were obtained from Anatomy departments of Minia and Cairo Universities and also from Forensic Medicine department of Justice Office in Minia governates – Egypt. Twelve measurements were taken for every talus. Data were analyzed by SPSS version 16. All measurements showed significant sexual differences ($P < 0.05$) except calcaneus articular surface width and navicular articular surfaced width. Talar length was found to be the most sexual dimorphic (90.9%). Combination of talar length, talar width and neck width gave a percentage of accuracy of 85.5%. Finally, it is concluded that the talus of Egyptian population is useful for sex estimation.

1. Introduction

Human identification is of a great importance in many anthropological cases and traumatic events (e.g. murder, mass disaster, aircraft crashes, automobile accidents, and archaeological remains). Within the medicolegal field, the objective of the forensic anthropologist when working with recovered skeletal remains is the determination of sex, stature, age and race.[1]

Many skeletal traits have been investigated in studies of sex identification of adult skeletons. Many studies had been done to estimate sex from bones using discriminant function analysis e.g estimation of sex from cranium,[2] mandible,[3] femur[4] and calcaneus.[5] Interest in the degrees and patterns of variation of these skeletal traits between males and females is related to the analysis of physical anthropology and to more practical purposes in forensic science (forensic anthropology).[2]

Sex estimation is the starting point in the forensic identification of skeletal remains. However, such remains are often fragmentary and there is a need to evaluate the contribution of any bone to sex estimation.[6,7]

There are several techniques in the field of forensic anthropology which make it possible to determine the demographics (e.g. sex and race) of the skeletal material under investigation. The 1st method depends on visual inspection and observation of sexual traits of bones and physical characteristics which are unique to individual elements of the human skeleton (wide subpubic angle in females and long and narrow occipital condyles in males). This method called morphological (non metrical method).[8]

The non metrical method can be used to obtain accurate results if the observer is expertise, and it is quicker than taking a measurement. The pelvis is considered to be the most accurate bone for sex determination as it allows for parturition in females.[9] Although the pelvis and mandible give accuracies close to 99% when using the morphological method, these bones are not always present in a forensic case. However, this method is a subjective method and requires more experience in the forensic field.[10,11]

On the other hand, the metrical methods (osteometry) based on measurements and statistical techniques such as Student *t*-test, use of demarking points and discriminant function analyses. The metrical methods used to estimate sex from bones (long bones and small bones of foot) that are not so obviously morphologically distinct.

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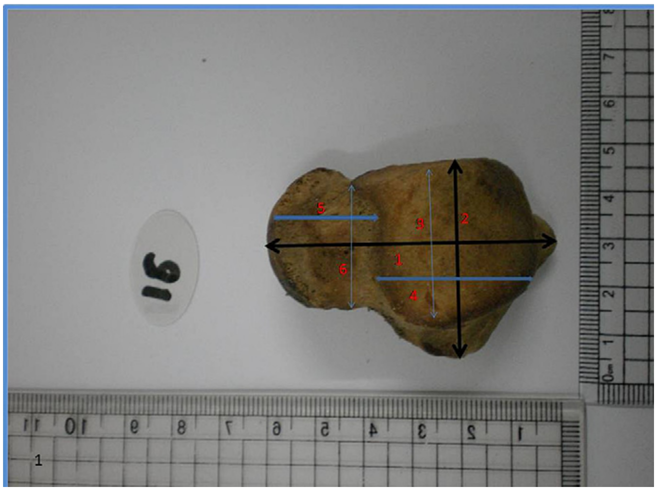

Fig. 1. Superior view of right talus showing talar length (TL) (black line No.1), talar width (TW) (black line No. 2), trochlear width (TW) (vertical blue line No. 3), trochlear length (TL) (horizontal blue line No. 4), neck length (NL) (blue line No. 5), and neck width (NW) (blue line No. 6). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

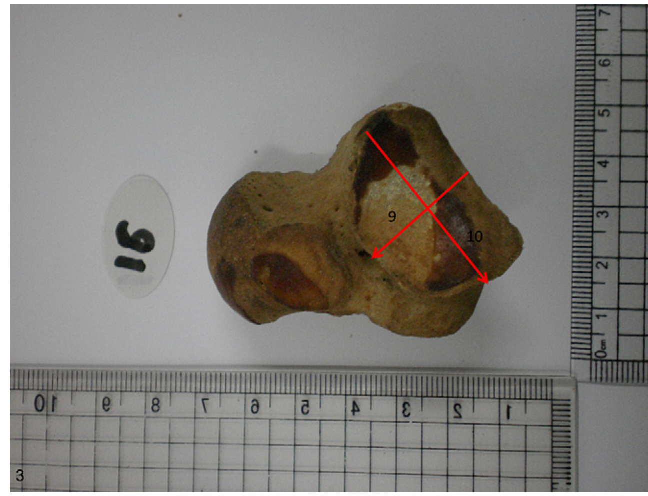

Fig. 3. Inferior view of right talus showing calcaneal articular surface length (CASL) (red line No. 9), and calcaneal articular surface width (CASW) (red line No. 10). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

These methods also require expertise and can be repeated to validate the results. The major disadvantage of them is that the mathematical equations derived from them are population specific and some measurements are difficult to take and require experience.[12]

Surface or even shallow burials often result in the loss of skeletal material which can greatly impede an investigation. Unlike the skull and long bones such as the femur or humerus, the compactness and the association of soft tissue (ligaments) makes the talus more resistance to taphonomic factors, thus increasing its chance of preservation and eventual field recovery. However, the feet are often removed from the body and taken away by animal activities, thus reducing the chances of finding the talus.[5]

In situations requiring postmortem identification where recovered skeletal material may be limited, this quality makes the talus an appropriate alternative for osteological analysis.[13,14]

The talus is the most proximal tarsal bone and consists of a head, neck and body. The head is directed distally and has an articulating facet for the navicular bone. The body has a trochlear surface which is convex anteroposteriorly and allows it to articulate with the tibia. Lateral to this surface, a facet for the lateral malleolus is present. Other major articulating facets found on the talus include the large posterior and the smaller anterior and the middle calcaneal surfaces found inferiorly.[13]

Discriminant function analysis has become important in forensic anthropology. If a measurement on a bone is suspected to be sexually dimorphic, it is subjected to discriminant function analysis.[15,16]

When a single measurement is used independently to determine sex, the univariate discriminant function analysis is used. However, when a combination of measurements is used, the method is termed multivariate discriminant function analysis which can either be stepwise or direct.[17,18] Therefore, the aim of this study is to assess the sexual dimorphism of the talus and derive discriminant function equations that would be useful in the determination of sex in Egyptian population.

2. Materials and methods

The tali used in this study were obtained from the departments of Anatomy of Minia and Cairo Universities and also from the

Fig. 2. Medial aspect of right talus showing talar height (TH) (blue line No. 7), and neck height (NH) (blue line No. 8). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 4. Anterior aspect of right talus showing navicular articular surface height (NASH) (blue line No. 11), and navicular articular surface width (NASW) (blue line No. 12). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Concordance correlation coefficient of reproducibility (Pc).

Variables	Pc
TL	0.99
TW	0.98
NL	0.97
NW	0.97
TRL	0.95
TRW	0.97
CASL	0.94
CASW	0.90
NASH	0.95
NASW	0.93
TH	0.96
NH	0.91

TL: talar length, TW: talar width, NL: neck length, NW: neck width, TRL: trochlear length, TRW: trochlear width, CASL: calcaneal articular surface length, CASW: calcaneal articular surface width, NASH: navicular articular surface height, NASW: navicular articular surface width, TH: talar height, NH: neck height.

Forensic Medicine department of justice office in Minia Governates- Egypt. These remains are mostly derived from the cadevers collection that is used for dissection by medical students and doctors of anatomy and Justice Office.

A total of 110 (67 male, 43 female) tali of Egyptian population whose age at death ranged between 20 and 60 years were measured. The period in the human history in which the bones belong to is unknown. The age and sex of tali were documented in the archives of Anatomy and Forensic Medicine department of Minia and Cairo Univerisities and Justice office in Minia Governates – Egypt. A simple random sampling technique was used in the selection of samples. The right talus was used in all cases. Those that were pathologic (fractured or broken) or considered deformed must be excluded from the study.

Twelve measurements were taken from each right talus using a manual vernier caliper. The 12 measurements are modifications of previous osteological studies.[19] All measurements followed Martin and Knussman's[20] definitions. The 12 measurements include talar length (TL), talar width (TW), neck length (NL), neck width (NW), trochlear length (TRL), trochlear width (TRW), calcaneal articular surface length (CASL), calcaneal articular surface width (CASW), navicular articular surface height (NASH), navicular articular surface width (NASW), talar height (TH), and neck height (NH) (Figs. 1–4). Digital photographs for the tali were done using digital camera, 10 megapixels, focused on 1.5. The tali were placed on a white background and photographs from superior, inferior, anterior and medial aspects at a distance of 20 cm were taken to show the measurements. All 12 measurements were repeated on 20 (10 male, 10 female) tali to assess the inter- and intraobserver repeatability. The repeatability of the technique was evaluated using the concordance correlation coefficient of reproducibility.[21]

Table 3
Demarking points (in cm) for sex differentiation using Egyptian individual variables (No. 110 tali).

Measurements	Demarking points
TL	Female $<$ 5.73 $<$ Male
TW	Female $<$ 3.99 $<$ Male
NL	Female $<$ 2.78 $<$ Male
NW	Female $<$ 2.88 $<$ Male
TRL	Female $<$ 3.76 $<$ Male
TRW	Female $<$ 3.31 $<$ Male
CASL	Female $<$ 4.97 $<$ Male
NASH	Female $<$ 3.4 $<$ Male
TH	Female $<$ 3.54 $<$ Male
NH	Female $<$ 3.28 $<$ Male

TL: talar length, TW: talar width, NL: neck length, NW: neck width, TRL: trochlear length, TRW: trochlear width, CASL: calcaneal articular surface length, NASH: navicular articular surface height, TH: talar height, NH: neck height.

2.1. Statistical analysis

The data were analyzed using SPSS statistical package version 16. Means and standard deviations were obtained for each of the measurements. After using a student t test to establish that a significance difference exists ($P \leq 0.05$) between the male and female measurements, discriminant function analysis (DFA) was performed. In univariate analysis, each of the significant measurements was individually subjected to discriminant analysis to test its efficiency in sex estimation. In stepwise and direct discriminant, the computer program selected a combination of measurements that diagnose sex perfectly from all the measurements entered. From these analyses, coefficients and constants were obtained for derivation of discriminant function scores and equations. Then, the cut point is derived which is the summation of discriminant function scores of males and females. For example, if the mean value for a measurement is greater than the female mean value and the discriminant score is greater than the cut point, the bone is classified as male.

Table 2
Descriptive statistics of the talus for Egyptian population (in cm).

	Male					Female					T- value	P value
	Number	Min.	Max.	Mean	S.D	Number	Min.	Max.	Mean	S.D		
TL	67	5.6	6.9	6.125	0.372	43	4.2	6.3	5.327	0.524	9.33	0.00*
TW	67	3.7	4.5	4.197	0.207	43	3.2	4.5	3.786	0.358	7.62	0.00*
NL	67	1.9	3.8	3.432	0.334	43	1.6	2.6	2.137	0.306	4.58	0.00*
NW	67	2.6	3.3	3.041	0.179	43	2.1	3.2	2.71	0.316	6.94	0.00*
TRL	67	2.9	4.9	4.253	0.276	43	2.5	3.7	3.269	0.354	4.9	0.00*
TRW	67	3	4.3	3.6	0.428	43	2.3	3.9	3.03	0.442	6.73	0.00*
CASL	67	2.2	3.2	2.582	0.272	43	1.8	3.2	2.395	0.408	2.98	0.00*
CASW	67	3.1	4.8	3.828	0.356	43	3.1	4.8	3.767	0.595	0.672	0.801
NASH	67	2.8	4.6	3.688	0.554	43	2.5	3.6	3.125	0.357	5.91	0.00*
NASW	67	2.8	5.2	4.295	0.557	43	3.8	4.7	4.307	0.332	0.122	0.903
TH	67	3	4.2	3.695	0.327	43	2.9	4.1	3.381	0.367	4.68	0.00*
NH	67	2.8	3.9	3.361	0.327	43	2.7	3.8	3.207	0.323	2.46	0.00*

TL: talar length, TW: talar width, NL: neck length, NW: neck width, TRL: trochlear length, TRW: trochlear width, CASL: calcaneal articular surface length, CASW: calcaneal articular surface width, NASH: navicular articular surface height, NASW: navicular articular surface width, TH: talar height, NH: neck height, S.D: standard deviation *P value is significant when $P < 0.05$.

Table 4
Correlation between different parameters of talus (No. 67 tali) in males (in cm).

	TL	TW	NL	NW	TRL	TRW	CASL	CASW	NASH	NASW	TH	NH
TL												
r					0.029		0.065					
P value					0.163		0.183					
TW												
r					0.060				0.093			
P value					0.196				0.117			
NL												
r				0.025								
P value				0.399								
NW												
r			0.015									0.067
P value			0.399									0.591
TRL												
r		0.061				0.089	0.024				0.064	0.078
P value		0.196				0.475	0.973				0.607	0.149
TRW												
r					0.089							
P value					0.475							
CASL												
r					0.004				0.014			
P value					0.973				0.913			
CASW												
r											0.054	
P value											0.215	
NASH												
r		0.093					0.014			0.049	0.063	
P value		0.117					0.913			0.229	0.188	
NASW												
r		0.063		0.051								
P value		0.189		0.685								
TH												
r				0.052	0.064			0.054	0.063			
P value				0.674	0.607			0.215	0.188			
NH												
r				0.067	0.076							
P value				0.591	0.149							

TL: talar length, TW: talar width, NL: neck length, NW: neck width, TRL: trochlear length, TRW: trochlear width, CASL: calcaneal articular surface length, CASW: calcaneal articular surface width, NASH: navicular articular surface height, NASW: navicular articular surface width, TH: talar height, NH: neck height.
[*]Correlation is significant if *P* value < 0.05.

3. Results

The result of the repeatability test showed that the range of values for the concordance correlation coefficient of reproducibility obtained in this study fell within the internationally standard of 0.90–0.99, as suggested by Cameron[22] (Table 1). This indicates that the measuring technique in this study is satisfactory.

Measurements of all parameters of tali in this study revealed that males presented with significantly greater ($P < 0.05$) mean values than females for all measurements except for CASW and NASW (there was insignificant differences in mean value in both sexes, $P > 0.05$) (Table 2), this indicating the presence of significant sexual dimorphism in the linear measurements of the Egyptians talus. The average of the male and female mean values gives the demarking points, in which the sum of male and female means divided on 2 (according to Bidmos and Asala[6]) (Table 3), which is a rapid way of determining sex from a single variable. A measured value higher than the demarking point classifies an individual as male and a lower value suggests female.

There was a significant strong correlation between different measurements with each other in both sexes. Tables 4 and 5 show the insignificant differences in males and females.

When the ten significant linear variables entered the univariate and multivariate discriminant function analysis, the percentage of accuracy was highest with the usage of talar length variable (90.9%) by univariate analysis. By direct discriminant analysis the best variables were TL, TW and NW with a percentage of accuracy of 85.5%. While, by stepwise analysis, the accuracy was 83.6% (Tables 6–9).

From these discriminant function (df) coefficient, df value for males and females can be calculated as follows:

(1) If TL is only used as by univrate analysis:
  df = standard coefficient (SC) × TL.
  df (males) = 0.412 × 6.125 = 2.524.
  df (females) = 0.412 × 5.327 = 2.195.
  Cut point = df (males) + df (females)/2 = 2.524 + 2.195/2 = 2.36.

So we can suspect the sex as follow: male if the df score is ≥2.36, if it is <2.36, the individual is considered female.

(2) If TL, TW and NW are used as by direct analysis:
  df = SC × TL + SC × TW + SC × NW.
  df (males) = 0.302 × 6.125 + 0.282 × 4.197 + 0.280 × 3.041 = 3.885.
  df (females) = 0.302 × 5.327 + 0.282 × 3.786 + 0.280 × 2.71 = 3.436.
  Cut point = df (males) + df (females)/2 = 3.885 + 3.436/2 = 3.66.

If the df score is ≥3.66, the individual is considered male and if it is <3.66, the individual is considered female.

Note: all measurements are in cm.

Table 5
Correlation between different parameters of talus (No. 43 tali) in females (in cm).

	TL	TW	NL	NW	TRL	TRW	CASL	CASW	NASH	NASW	TH	NH
TL												
r									0.038	0.044	0.046	
P value									0.808	0.780	0.112	
TW												
r									0.064	0.083		
P value									0.683	0.596		
NL												
r											0.087	
P value											0.581	
NW												
r			0.431					0.086			0.055	0.039
P value			0.399					0.583			0.320	0.374
TRL												
r		0.724									0.093	0.051
P value		0.196									0.216	0.754
TRW												
r									0.035	0.029	0.070	0.024
P value									0.388	0.408	0.275	0.149
CASL												
r					0.630				0.025			
P value					0.973				0.872			
CASW												
r				0.086					0.014			
P value				0.583					0.929			
NASH												
r	0.038	0.064	0.015			0.035	0.025	0.014			0.060	
P value	0.808	0.683	0.504			0.388	0.872	0.929			0.703	
NASW												
r	0.044	0.083				0.029						
P value	0.780	0.596				0.408						
TH												
r			0.087	0.055	0.093	0.070			0.060			
P value			0.581	0.320	0.216	0.275			0.703			
NH												
r				0.039	0.051							
P value				0.374	0.754							

TL: talar length, TW: talar width, NL: neck length, NW: neck width, TRL: trochlear length, TRW: trochlear width, CASL: calcaneal articular surface length, CASW: calcaneal articular surface width, NASH: navicular articular surface height, NASW: navicular articular surface width, TH: talar height, NH: neck height.
*Correlation is significant if *P* value < 0.05.

4. Discussion

In the forensic and archaeological context, one of the methods utilized for sex determination of skeletal remains is discriminant function analysis. The use of discriminant function equations to sex unidentified skeletal remains is now a frequent practice.[23] The existence of significant sexual dimorphism in the dimensions of the Egyptian talus has been confirmed by the present study. The talus has been described as being one of the most durable bones of the foot.[24] Thus, the discriminant functions derived in the present study will be of considerable utility to investigators in the forensic science since the measurements used involve a preservationally favoured portion of the skeleton.

All variable measurements in the present study were more than the measurements taken by Bidmos and Dayal,[19] on a sample of South African Whites (e.g. the length for Egyptian males and females were 6.125 & 5.327 cm respectively, and for South African Whites, males and females were 5.561 and 5.11 cm. This difference can be the result of genetic factors and environmental factors affecting the growth and development.[25]

Independent samples *t*-test was done for all males and females' samples, the results revealed that there was significant difference between male and female tali in all measurements except CASW and NASW. The significant differences between males and females tali are due to differences in body size and in muscular activity of the individual, also cortical bone in males has higher growth than in

Table 6
Univariate discriminant function analysis (No. 110 tali).

Variable	Standardized coefficient (SC)	Constant	Accuracy
TL	0.412	−5.82	90.9%
TW	0.329	−5.24	81.8%
NW	0.320	−5.79	81.8%
TRW	0.255	−2.98	69.2%
CASL	0.250	−1.76	70.4%
NASH	0.125	−2.68	65.5%
TRL	0.212	−3.04	63.9%
TH	0.128	−2.58	63.9%
NH	0.121	−1.48	63.9%
NL	0.112	−2.62	51.8%

TL: talar length, TW: talar width, NL: neck length, NW: neck width, TRL: trochlear length, TRW: trochlear width, CASL: calcaneal articular surface length, NASH: navicular articular surface height, TH: talar height, NH: neck height.

Table 7
Multivariate discriminant function analysis (No. 110 tali).

Function analysis	S.C	Constant	Accuracy
Direct:			
TL	0.302	(−6.647)	(85.5%)
TW	0.282		
NW	0.280		
Stepwise:			
TL	0.221	(−11.053)	(83.6%)
CASL	0.162		

TL: talar length, TW: talar width, NW: neck width, CASL: calcaneal articular surface length; SC: standardized coefficient.

Table 8
Summary of canonical discriminant functions for Egyptians (No. 110 tali).

Functions	Eign value	% of variance	Cummulative %	Canonical correlation	Wilks Lambda	Chi. Sq.	Sig.
Direct:							
Three linear variables	0.212	100	100	0.422	0.822	6.82	0.000
Univariate:							
TL	0.115	100	100	0.392	0.421	7.8	0.000
TW	0.108	100	100	0.387	0.511	6.7	0.000
NW	0.820	100	100	0.299	0.408	7.2	0.000
TRW	0.122	100	100	0.250	0.411	6.5	0.000
CASL	0.126	100	100	0.350	0.523	7.9	0.000
NASH	0.139	100	100	0.211	0.608	6.8	0.000
TRL	0.198	100	100	0.315	0.551	5.9	0.000
TH	0.121	100	100	0.309	0.617	6.8	0.000
NH	0.202	100	100	0.388	0.682	5.7	0.000
NL	0.209	100	100	0.288	0.722	6.4	0.000
Stepwise:	0.189	100	100	0.282	0.625	5.95	0.000

TL: talar length, TW: talar width, NL: neck length, NW: neck width, TRL: trochlear length, TRW: trochlear width, CASL: calcaneal articular surface length, NASH: navicular articular surface height, TH: talar height, NH: neck height.

Table 9
Percentage of cases correctly classified.

Functions	Variables	Total	Males		Females		Accuracy
			%	No.	%	No.	
Univariate	TL	110	91.04	61/67	90.7	39/43	90.9%
	TW	110	82.1	55/67	81.4	35/43	81.8%
	NW	110	82.1	55/67	81.4	35/43	81.8%
	TRW	110	68.7	46/67	69.8	30/43	69.2%
	CASL	110	68.7	46/67	72.1	31/43	70.4%
	NASH	110	65.7	44/67	65.1	28/43	65.5%
	TRL	110	62.6	42/67	65.1	28/43	63.9%
	TH	110	62.6	42/67	65.1	28/43	63.9%
	NH	110	62.6	42/67	65.1	28/43	63.9%
	NL	110	52.2	35/67	51.1	22/43	51.8%
Direct	TL, TW, NW	110	85.1	57/67	86	37/43	85.5%
Stepwise	TL, CASL	110	83.6	56/67	83.7	36/43	83.6%

TL: talar length, TW: talar width, NL: neck length, NW: neck width, TRL: trochlear length, TRW: trochlear width, CASL: calcaneal articular surface length, NASH: navicular articular surface height, TH: talar height, NH: neck height.

females.[15] These results are agree with a study done for South African Whites by Bidmos and Dayal[19] which also found that there is a significant differences between males and females in all measurements except CASW.

Univariate discriminant function analysis revealed that talar length is the best variable can be used for sex determination of the talus in Egyptians, the accuracy was 90.9%. Accuracy was similar for talar width and neck width (81.8%), lastly by using calcaneal articular surface length, the accuracy was 70.4%. So, length measurement was the most sexually dimorphic for Egyptian population. This result is similar to that of Bidmos and Dayal[19] on a sample of South African Whites, as the length measurement was the most sexually dimorphic with average accuracy 81.7%.

By using direct and stepwise discriminant function analysis, it was found that the accuracy of using three linear measurements (TL, TW and NW) in sex determination for Egyptians was(85.5–83.6%). These results are in contrast with that obtained by Murphy[23] in which his study on a sample of New Zealand Polynesians revealed that the accuracy of using different linear measurements (TL, TRW and TRL) was 85.1–91.3) by direct and stepwise discriminant function analysis respectively.

5. Conclusion & recommendations

This study has shown that measurements of talus of Egyptians are sexually dimorphic. The level of accuracy obtained from the use of TL by univariate analysis was 90.9%. By direct discriminant function analysis, the level of accuracy obtained from (TL, TW and NW) was 85.5%. So, it is recommended that the equation derived from this study should be used with caution in cases when talus is available for determination of sex of Egyptian population.

Conflict of interest

There is no conflict of interest between any of the authors.

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Ethical approval

No ethical approval is required.

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